⑫ **EUROPEAN PATENT APPLICATION**

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�554 Position sensing apparatus.

�557 An unenergised member (60) moves relative to an extended single phase energised primary coil system (12) and a secondary coil system (11). The coils of the secondary coil system are in series connected pairs (coils 11A, 11G in pair 11/1) interspaced with other pairs (coils 11B, 11H in pairs 11/2) as an array of coils along a path (x) which may be straight, curved, etc. The coils in the pairs, which are balanced to give a zero output, form sequences (sequences I, II, III etc) each of which are terminated with a phase-shift network (PC) to give an incremental phase shift between sequences. The incremental phase-shifted outputs are combined to give a progressive phase-shifted output (66) representative of the position of the member (60). Ambiguity avoidance, when phase shift exceeds 360°, may be arranged (Figures 8 and 9) by having two secondary coil systems (81A, 81B) with the same number of coils but with differing inremental phase-shifted outputs so that the utilised progressive phase-shifted output is a phase difference (C in Figure 9).

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Fig. 6

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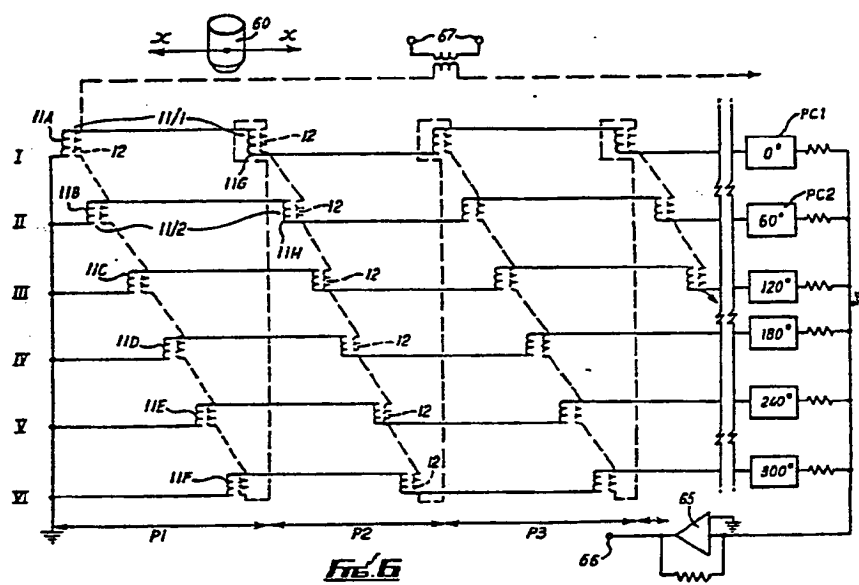
POSITION SENSING APPARATUS

This invention relates to position sensing
apparatus of the kind having primary and secondary coil
systems defining a path in which position of a member on,
5   and dimensionally much smaller than, said path is
represented by a characteristic phase output.

Such apparatus is broadly known and in this respect
reference is made, by way of example, to British Patent
Specifications numbered 1 259 787 and 1 406 217 and
10   European Patent No. 0012138.

Of the inventions disclosed in these three
references, that in EU 0012138 has met with significant
commercial success but it does require a pen or cursor
carrying the secondary system to which leads have to be
15   connected. These are troublesome and become even more
troublesome where the apparatus has to function in harsh
or hostile environments. As a first step in the present
invention is the concept, not novel in itself (see GB
1 406 217), of having an unenergised moving member, such
20   as one of magnetic material, as a pen or cursor so that
no connecting leads are required thereto. The invention
of 1 406 217 has worked satisfactorily in laboratory
conditions but has not had the robustness or elegance for
commercial use. It requires, for example, a multiphase
25   energisation of three or more primary coil

systems and a secondary multi-turned coil (sometimes
in two parts or arranged on-side vertically). The
tolerances required to give a nominally zero output in
the absence of the moving member of magnetic material
5   (an essential for operation) are difficult to achieve
at low cost. Further, the need to remove ambiguity when
the total phase change exceeds 360° has to be met by a
further primary and secondary coil system. Yet further,
an acceptable standard of position sensing is only
10   achieved by the member of magnetic material penetrating
through the secondary coil system. The invention
disclosed in GB 1 406 217 is not ideal   for use in a
harsh, hot, or hostile environment.

The present invention uses a single phase-energised
15   primary coil system which can be a single coil or an
array of coils each with only a single or a few turns
preferably presented with very shallow depth on a
printed circuit board. The secondary coil system, which
is in the form of an array of coils, provides the
20   output phase related to the movement of a pen or other
unenergised member. Ambiguity arising when a phase
change exceeds 360° can be met with a further secondary
coil system without a further primary coil system. The
coils of the apparatus can be laid down on a printed
25   circuit board to give low cost manufacture, high

stability, robustness, flexibility in design, the necessary close coupling, and high accuracy.

The present invention provides position-sensing apparatus of the kind above stated in which the movable

5   member is an unenergised member devoid of electrical connections which can serve as a flux-coupler between the coil systems and whose position on the path defined by the coil systems is represented by output from the secondary coil system, said output being nominally zero

10   in the absence of said member, characterised in that:

(a)   the primary coil system is adapted to be single-phase energised;

(b)   the coils of the secondary coil system are:

(i) disposed series connected in pairs

15   interspaced with other pairs as an array of coils along said path (straight, curved, circular etc),

(ii) placed relative to the primary coil system so that on energisation of the primary coil system the two coils of any pair have reversed

20   polarity signals to generate said nominally zero output, and

(iii) located relative to a path of movement of the unenergised member so that they are close coupled with said member;

25   (c)   phase shift networks for each pair, or series connected sequence of pairs of secondary coils, said networks giving an incremental phase shifted

output as between one pair, or sequence of series
connected pairs, and the next; and

(d)   means combining the incremental phase shifted
outputs to give a progressive phase shifted output so

5   that the position of the unenergised member is
represented by said progressive output.

The unenergised member is preferably of magnetic
material such as a ferrite. It is possible for the non-
magnetic material to be a conductive ring, but signal

10   strengths would then be much weaker.

The primary coil system may comprise a coil which
lays over or around the coils of the secondary coils
system or it may comprise an array of coils individual
to respective coils of the secondary coil system such as

15   provided by bifilar winding of primary and secondary
coils. In the latter case, the reversed polarity signals
can either be generated by reversing the polarity of the
secondary or the primary coils. In the former case the
reversed polarity signals are generated by reversing the

20   polarity of the secondary coils.

The primary coil system may be in two parts so
that the unenergised member can pass between the two
parts.

The coils of the secondary coil system may be

25   arranged in successive pitches, each pitch representing
360° phase change with means resolving ambiguity
between pitches. Said means could be provided by having
further primary and secondary coil systems differing

from the first so that two progressive phase shifted
outputs are obtained which can be processed to give an
unambiguous output. Said means could also be provided
in the form of a further secondary coil system only, with
5   the same spacing between coils as in the first secondary
coil system and with the same number of coils but having
more or less coils per pitch so that a progressive phase
change output can be obtained which is the phase
difference between the two secondary coil systems. When
10 presented on a printed circuit board this provides a very
compact system with substantially no space penalty being
required for the ambiguity removal means and with
relatively simple circuitry.

   As there is close coupling between the unenergised
15 member and the secondary coils there is a tendency for
smooth progression to be lost at the output. This can
be avoided by suitable shaping of the magnetic member.
One form of member shaping is provided by having edge
chamfering so that the closeness of coupling is changed
20 at the edge region of the member.

   The unenergised member may have multiple parts with
the parts moving together but spaced apart. Typically
one part is spaced from another so as to be represent-
ative of 360° advance. In this way very similar signals
25 are generated from both, or all, multiple parts. The
signals can then be added together to give an output
signal which has an improved signal-to-noise ratio and
which averages out local errors to improve linearity.

Where an array of secondary coils has a primary
coil over or around the array, the coils in the array
will not have identical e.m.f's induced in them as their
individual space locations relative to the primary

5   differ. This would act, if not corrected, to give a
measureable output in the absence of the unenergised
member and this must not occur. Correction can be
effected by having differing numbers of turns in the
coils of the secondary system. Where this expedient

10   does not make an exact correction then there could be an
adjustment to the closeness of the windings in the
secondary coils or other shape adjustments, such as
length, made to the coils.

Various forms of the invention will now be described

15   by way of example with reference to the accompanying
drawings in which:

        Fig. 1 is a circuit diagram showing a single primary
            coil and a linear array of secondary coils;

        Fig. 1A is a circuit diagram showing certain coils

20   of the secondary system arranged serially in
            reversed polarity pairs;

        Fig. 2 is a circuit diagram showing an array of
            primary coils each bifilar wound with an
            associated secondary coil;

25   Fig. 3 is similar to Fig. 1 but shows a circular
            array;

Fig. 4 is similar to Fig. 1 but shows the
secondary coils in a wrapped-round
configuration;

Fig. 4A is an explanatory end view diagram;

Figs. 5A and 5B illustrate the electrical output
effect of an unenergised pen passing over a
single secondary coil;

Fig. 6 is a circuit diagram showing primary and
secondary coil arrays with respective
incremental phase advance (or retard) units
in a multiple pitch secondary array.

Fig. 7 shows a circuit for processing the output
of the circuit of Fig. 6;

Fig. 8 is a sectional diagrammatic view of primary
and secondary coil arrays on a printed
circuit board;

Fig. 9 is a graph showing the co-relation between
outputs of two secondary arrays;

Figs. 10 and 11 arrays in which movement of an
unenergised member which deviates from a
true co-ordinate direction can be
identified;

Fig. 12 shows coil arrangements in one axis of a
two axis array;

Figs. 12M and 12N show enlarged cross sections on
the lines M and N of Fig. 12.

Fig. 13 illustrates an arrangement having an
unenergised member having two parts with
the parts spaced apart and moving
together;

5   Fig. 14A shows a shaped member of magnetic
material which can be used in a movement
encoder such as on a rotary or linear
moving shaft; and

Fig. 14B shows a shaped member of magnetic material

10   which can be used as a pen.

In Fig. 1 a position sensing apparatus 10 has a
secondary coil system consisting of three interspaced,
series connected, sequences I, II, III, of coils 11
each having terminals S and F and shaped to have a

15   length greater than its width and each mounted with its
major axis lateral to that of adjacent coils and
functionally defining a co-ordinate direction "x".
(In practice more than three sequences of coils would
be used - see Fig. 6). The coils 11 in each sequence

20   are connected in reversed polarity as illustrated in
Fig. 1A (which has isolated the coils in sequence I
from the other coils). The coils 11 and 12 are
preferably of shallow depth such as provided by a
printed circuit board. The coils 11 present "pitches"

25   P1, P2 each representing 360° of phase change.

The apparatus 10 has a primary winding 12 with a

length greater than its width and mounted across the

coils 11 with its major axis in the co-ordinate

direction "x". The winding 12 could lie around the

5   coils 11 as shown in Fig. 12 for example. The primary

winding 12 is stimulated from a single phase A.C. supply

13. With no movable magnetic member in the vicinity of

the windings the voltage at the output 14 (Fig. 1A) of

the secondary coil sequence is zero or acceptably very

10   small (such as about 1% of the output when a magnetic

member is present). The coupling between the magnetic

member and the secondary coils is close and is equal

for all coils 11 in any one sequence although some loss

of equality can be accepted where the apparatus is used

15   in conjunction with a ~~micro~~ microprocessor adapted to adjust for

linearity errors. The end coils 11 in Fig. 1 are closer

to the end of the primary winding than the central ones

and therefore have a slightly greater flux linkage. To

correct for this the coils 11 in the secondary system

20   can differ from one another, such as having a differing

number of turns, differing shape, differing density of

turns etc. as shown in Fig. 12.

In Fig. 2 the primary system is shown as a number

of coils 12A, 12B etc. bifilar wound with coils 11.

25   The coils 12A etc. are connected in series with no

reversals whilst the coils 11 retain the reversals of

polarity referred to above. In an alternative the

coils 12A could have reversed polarity and the coils 11

are then not reversed. The bifilar winding gives a

closer coupling but is mainly advantageous in reducing

the number of layers required when a printed circuit

board design is adopted and thereby reduce the cost of

5   the apparatus.

Fig. 3 shows a circular construction of the

apparatus having a base 30 and radial secondary coils

31 and a primary winding in two parts 32A and 32B to

allow magnetic material 33 to pass between them. Again

10   the primary windings 32A, 32B could be around (outside)

the secondary coils 31.

Fig. 4 shows a cylindrical construction of the

apparatus comprising a tubular base 40 having secondary

coils 41 with a primary winding 42 which can be bifilar

15   wound with the coils 41 or, as actually shown in Fig. 4,

the primary can lay across the secondary coils.

Fig. 4A shows a magnetic member, such as a ferrite

rod 43. If the rod 43 is constrained to move only along

the base 40 then the construction shown in Fig. 4 is

20   suitable. If the rod 43 is free to rotate about the

axis of the base 40 then the bifilar construction is

preferred.

The effect of the presence of magnetic material

will now be considered with reference to Figs. 5A and B.

25   In Fig. 5A a cylindrical piece of ferrite 50 is

moved in the "x" direction above a secondary coil 51

having a current induced in it from a primary winding

52. In Fig. 5B the effect of this movement is shown by

graphs of output voltage from the coil 51: graph G1
shows the output voltage received from bifilar wound
primary/secondary and graph G2 shows the output voltage
which is received from the Fig. 5A arrangement.

5 (In both graphs G1 and G2 a standing output voltage
exists by virtue of coupling in the absence of the
ferrite 50 but this has been subtracted).

In Fig. 6 a more detailed circuit arrangement is
shown than that of Fig. 1. Pitches P1, P2 etc. (each

10 representing 360° of phase change) of secondary coils
11A, 11B etc. are provided with six coils per pitch and
the pitches follow each other in a given line (e.g.
straight line for Fig. 1 or a circular line for Fig. 3).
The secondary coils 11 are bifilar wound with series

15 connected primary coils 12. Respective coils 11 in each
pitch are reverse polarity connected in pairs such as
interspaced pairs 11/1, 11/2, and in sequences I, II
etc. and the final coil in each sequence is connected to
a respective incremental phase change (advance or retard)

20 unit PC1, PC2 etc. With six coils 11 per pitch the
phase change between adjacent chains is 60°; five coils
is 72°; four coils is 90°; "n" coils is $360/n°$. The
output from all the units PC is taken through a feed-
back amplifier 65 to an output 66. A reference input 67

25 is applied to the coils of the primary system. The
phase at output 66 measured in relation to the input 67
is representative of the position of a member of magnetic
material along the array of coils. In the absence of

magnetic material no significant output is obtained at
output 66.

The input 67 is of high quality sinusoidal form
of about 10 KHz. Instead of reversing the polarity of
5   the coils 11 the polarity of coils 12 could be
reversed.

The output is suitable for analogue or digital
applications such as transducers or encoders,
operating in a linear or rotary mode. Apparatus
10   according to the invention can be made to operate
immersed in oil, in smoke, heat and radioactive
conditions. Measurement accuracy is not too critical
as the invention, which is suitable for working with
micros, can accommodate a degree of error by correction
15   elements in the micro programming. There is no call
for slip rings or moving wires and hence there is the
capability for the utmost reliability in the severest
conditions. Whilst the movable member is preferably of
magnetic material similar but small amplitude signals
20   can be obtained with, for example, a movable conductive
ring.

The processing of the signals derived from Fig. 6
is now illustrated with reference to Fig. 7. The
primary input 67 is taken to an amplifier 70 and
25   squarer 71 and the secondary output 66 is taken to a
corresponding amplifier 72 and squarer 73. The leading
edges of the output of the squarers 71, 73 are utilised
in a latch 74 (bistable) to derive respectively the leading and

trailing edges of a square pulse which has its length

measured in terms of pulses from a clock pulse

generator 75 at an AND gate 76. This length is

representative of phase difference between 67 and 66 and

5   hence is representative of the position of a member

moving along the array. This position is presented on

a digital meter 77.

The circuit of Fig. 6 becomes ambiguous as between

one pitch and any other after the first six coils 11A -

10 11F have been passed by the moving member. This

ambiguity can be removed by having further but different

primary and secondary coil systems affected by the

moving member. Typically this could give a further

reading at a further meter 77. The two readings of the

15 counters could be processed to give unambiguous inform-

ation.

However, an improved unambiguous system in

accordance with the invention can be obtained by having

two differing secondary coil systems and taking the

20 phase difference between the secondary coil systems as

an unambiguous position measurement. This will now be

illustrated with reference to Figs. 8 and 9.

In Fig. 8 a printed circuit board 80 has an upper

array of secondary coils 81A on its upper face and a

25 lower array of secondary coils 81B on its lower face.

The arrays are like that shown in Fig. 6. The primary

system comprises coils 82A and 82B bifilar wound with

coils 81A and 81B. The coils 81A are grouped twelve to

a pitch (phase change of 30° per coil) and the coils
81B are grouped fourteen to a pitch (phase change of
360/14° per coil). The spacing between coils is the
same for both arrays. The output from these arrays

5   are as shown in the graph of Fig. 9, namely, as a
member of magnetic material moves along the array, there
is a 360° phase change for each twelve coils of the
upper array traversed and a 360° phase change for each
fourteen coils of the lower array traversed. The

10   difference in phase between the outputs 81A and 81B is
represented by C and this is not ambiguous up to a
maximum of a very large number of coils.

At certain points (e.g. C') the difference C will
be measured as negative. When this is detected the

15   actual value of C (which lies partly below 81A and
partly above 81B) can be resolved by adding in a
positive constant representative of the 360° ordinate.

This system describes with reference to Figs. 8
and 9 lessens the risk of linearity errors.

20   In an alternative, the primary bifilar wound
coils could be replaced with a single primary like
that shown in Fig. 1 but these would require a multi-
layer printed circuit board.

In another system the coils need not have the same

25   spacing nor the same numbers. A multilayer board is
required. In such systems, to avoid one secondary
system distorting the other, the primary system should
be like that shown in Fig. 3.

The arrangement of Fig. 8 can be a linear scheme
(like Fig. 2) or a circular scheme (like Fig. 3). The
circular scheme on a single printed circuit board
imposes the limitation that the coils of the upper and

5   lower arrays must be of an even number. The Fig. 8
scheme may have, for example, in the upper array seven
pitches each of twelve coils with a phase change (PC)
of 30° and in the lower array six pitches each of
fourteen coils with a phase change of 25.7°. An

10   alternative scheme could have four pitches each of six
coils with a phase change of 60° or three pitches each
of eight coils with a phase change of 45°. Other
combinations are possible.

In Fig. 10 the primary and secondary coils 11, 12

15   have been given a very pronounced length to width ratio
and they are inclined to each other. This gives an
output which is related to deviations in the "y"
co-ordinate direction of a magnetic member which can
move over them. The multiple coils 12 can be replaced

20   with a single coil 12 in the manner of Fig. 1. This is
illustrated in Fig. 11. The coils 11 now provide A and
B inclined pairs.

Using this arrangement a deviation of a moving
member from a given line can be determined. Whilst

25   this is usually not significant in a linear system it
is of value in a circular system where deviation from
the given line may represent eccentricity of movement
of the moving member. Such eccentricity gives rise to

a positional error. If the eccentricity can be measured

then correction of the error can be made electrically.

With skewed coils (like Figs. 10 and 11) small two axis

encoders are possible.

5   A two-axis printed circuit board arrangement is

possible. One axis is shown in Fig. 12. The secondary

coils 11, are provided within the boundary defined by the

primary coil 12. These are seen to vary in length, as an

element in the balancing of the coils. They also vary in

10   number of turns and density as illustrated by Figs. 12M

and 12N. On the section represented by Fig. 12M four

windings M11 of relatively lower density are provided

whilst in Fig. 12N three windings N11 of higher density

exist.

15   In Fig.13 a shaft encoder is shown having secondary

coils 11 arranged around the walls of a cylinder 95.

The primary coil, or coils, are not shown but are

provided in any of the ways above described. A shaft 93

has two arms 94 located at an angle to each other and

20   the arms carry blades 96 of ferrite which move over the

inside wall, and the secondary coils, of the cylinder.

Coils 11 are provided and they are connected to form a

number of pitches and further coils, in the manner of

Fig. 8, form differing pitches. Two outputs from the

25   pitches are obtained by virtue of the two arms and

these are combined to give an

improved signal-to-noise ratio with a degree of
averaging of any errors.

In Fig. 14A the cross-section of the blades 96 are
shown in to an enlarged scale and relative to a coil 11.
5   The blade has a tapered part 96A. This, for the given
conditions, gives a smooth progression of the phase
shifted output from the coils 11 as the blades 96
move   over the coils.

In Fig. 14B a pen 98 is shown. This has a
10   cylindrical ferrite 97 with a tapered point 97A.
Through the core of the cylinder a part 99 of the body
of the pen extends. A coil 11 is shown. The lowermost
point of the ferrite 97 is spaced from the coil 11 by a
distance equal to 0.50 times the width $\underline{w}$ of the coil.

CLAIMS:

1. Position sensing apparatus having primary and
secondary coil systems defining a path (x) and an
unenergised movable member devoid of electrical
5   connections which is dimensionally much smaller than said
path which can serve as a flux-coupler between the coil
systems and whose position on the path defined by the
coil systems is represented as a progressive phase-
variable output from the secondary coil system, said
10 output being nominally zero in the absence of said
member, characterised in that:

(a) the primary coil system (12) is adapted to be single-
phase energised:

(b) the coils (11A, 11B.. etc) of the secondary coil
15 system (11) are:

   (i) disposed series connected in pairs (e.g. coils
   11A, 11G in pair 11/1) interspaced with other pairs
   (coils 11B, 11H in pair 11/2) as an array of coils
   along said path (straight, curved, circular etc),

20   (ii) placed relative to the primary coil system so
   that on energisation of that system the two coils of
   any pair have reversed polarity signals to generate
   said nominally zero output, and

   (iii) located relative to the movement of the
25   unenergised member (60) so that they are close
   coupled with said member;

(c) phase shift networks (PC1, PC2 etc) for each pair,
or series connected sequence (I, II, III etc) of pairs

of secondary coils, said networks giving an
incremental phase shifted output as between one pair,
or sequence of series connected pairs, and the next;
and

5   (d)   means (65) combining the incremental phase
shifted outputs to give a progressive phase shifted
output (66) so that the position of the unenergised
member is represented by said progressive output.

2.   Apparatus as claimed in Claim 1 in which the
10   primary coil system comprises a coil which lies over
(Fig. 1:Fig. 3) or around (Fig. 12)   the
secondary coil system.

3.   Apparatus as claimed in Claim 1 in which the
primary coil system comprises an array of coils
15   individual to respective coils of the secondary coil
system (Fig. 2; Fig. 6).

4.   Apparatus as claimed in Claim 1 in which the coils
(81A in Fig. 8) of the secondary coil system are
arranged in successive pitches (P1, P2 etc. in Fig. 6)
20   with each pitch representing $360°$ of phase change with
means resolving ambiguity between the pitches, said
means comprising a further secondary coil (81B)
system with the same spacing between coils as in the
first secondary coil system but having more, or less,
25   coils per pitch so that a progressive phase shifted
output (C in Fig. 9) is obtained which is the phase

difference between the two secondary coil systems.

5. Apparatus as claimed in any preceding claim in which the unenergised member is shaped to give a smooth progression of the phase shifted output as the member moves across the coils of the secondary coil system.

6. Apparatus as claimed in Claim 2 in which the coils of the secondary coil system are individually shaped to give said nominally zero output.

7. Apparatus as claimed in any preceding claim in which the unenergised member has multiple parts with the parts spaced apart and moving together (Fig. 13)

8. Apparatus as claimed in Claim 1 in which the coils (31) of the secondary coil system are disposed on a circular array.

9. Apparatus as claimed in Claim 1 in which the coils of the coil systems are given an oblique disposition whereby a deviation from movement of the unenergised member along a pure direction (x) can be detected.

10. Apparatus as claimed in any preceding claim in which the unenergised member has its surface located relative to the coil systems by no more than one half the transverse dimension of the coils of the secondary coil system.
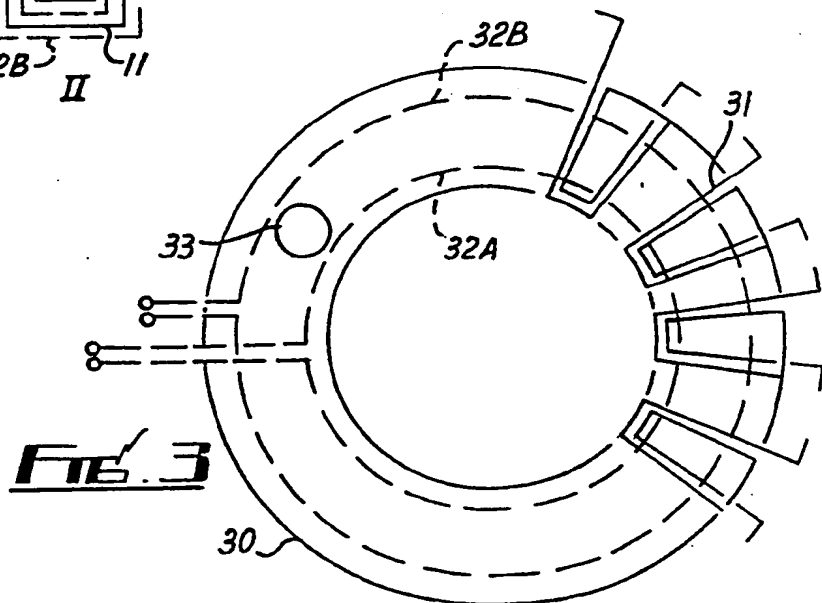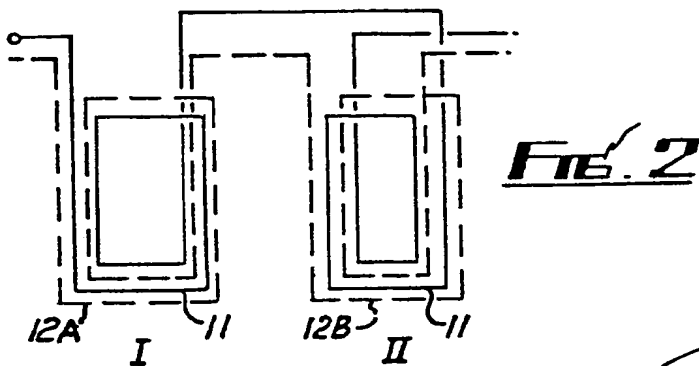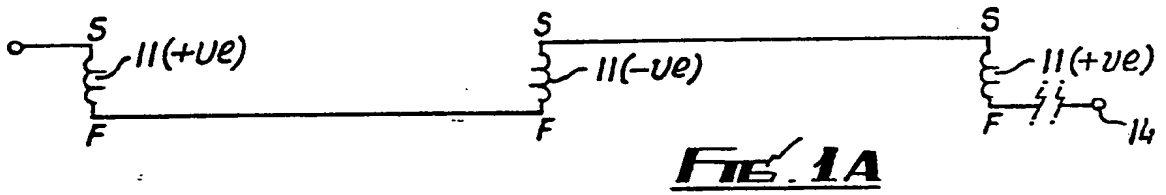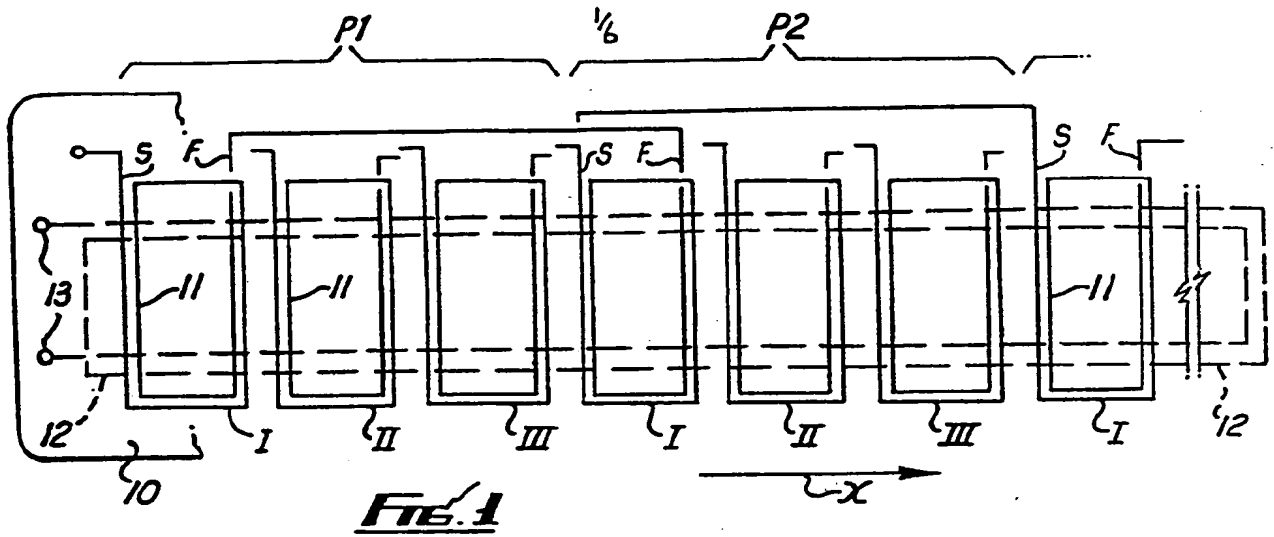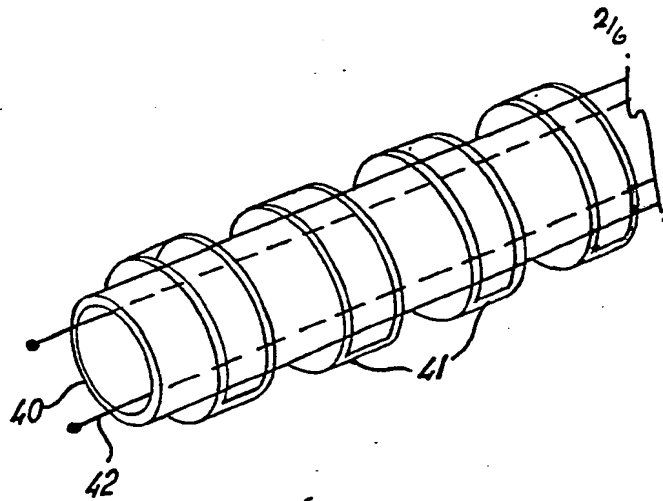
Fig.1

Fig.1A

Fig.2

Fig.3

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Fig.4

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Fig.4A

52

50

"X"

52

51

11

Fig.5A

G2

G1

"X"

Fig.5B

FIG. 6

4/6

Fig.7
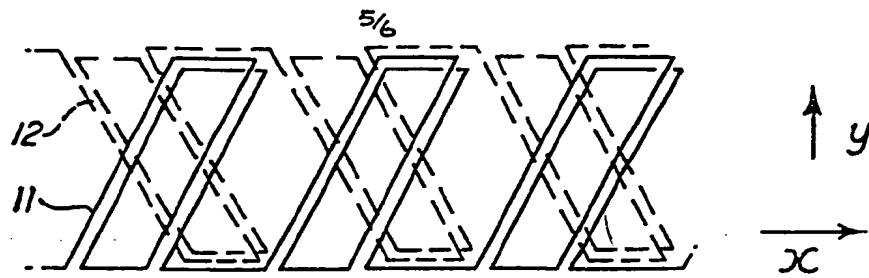

Fig.8

Fig.9

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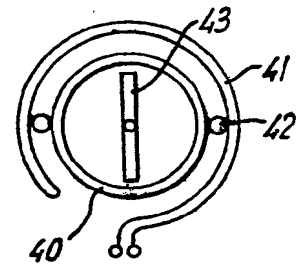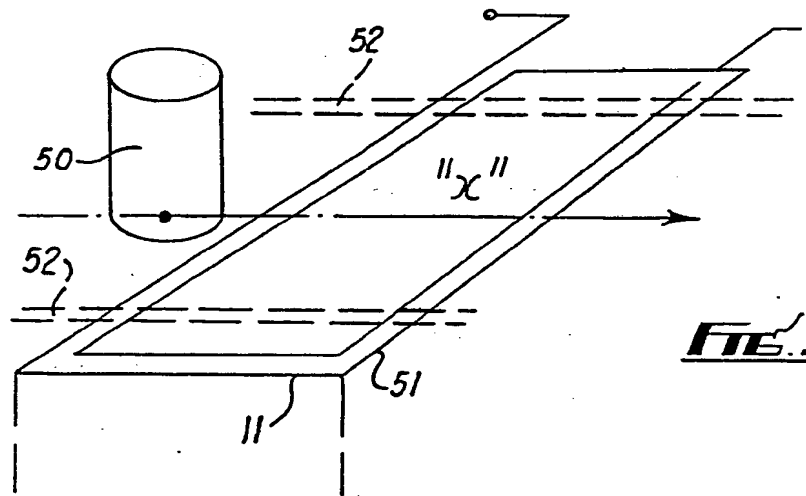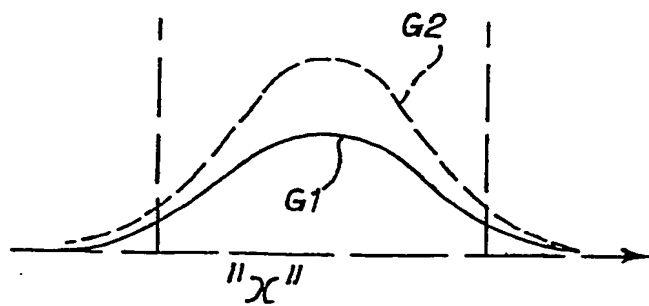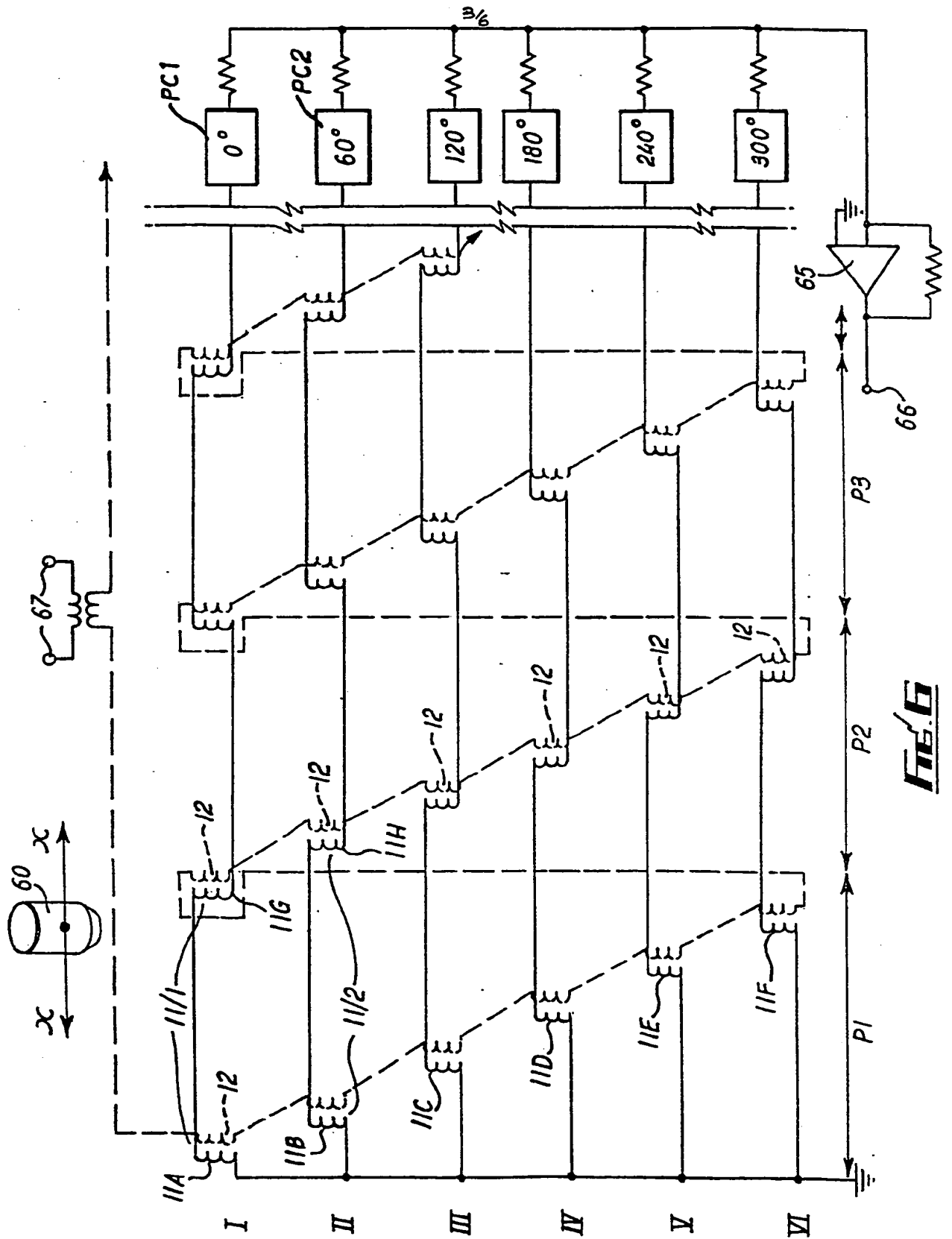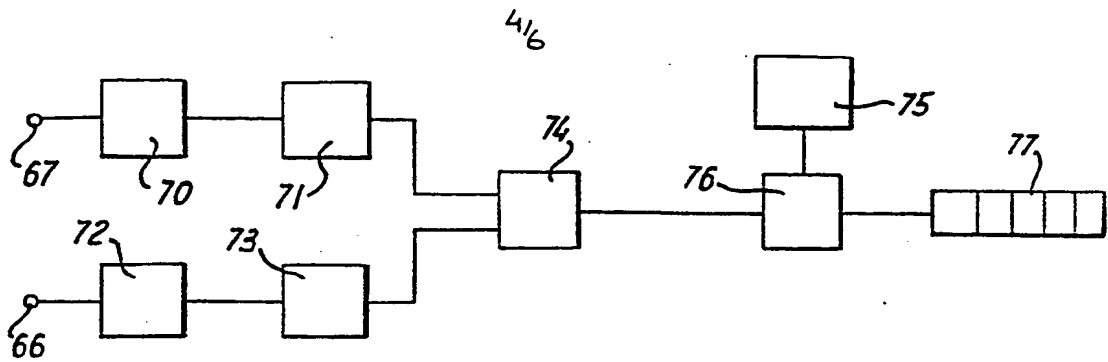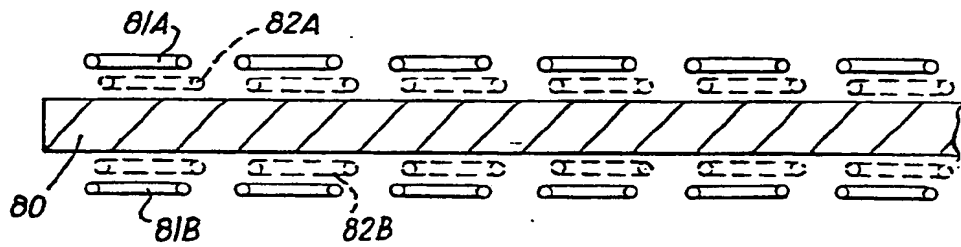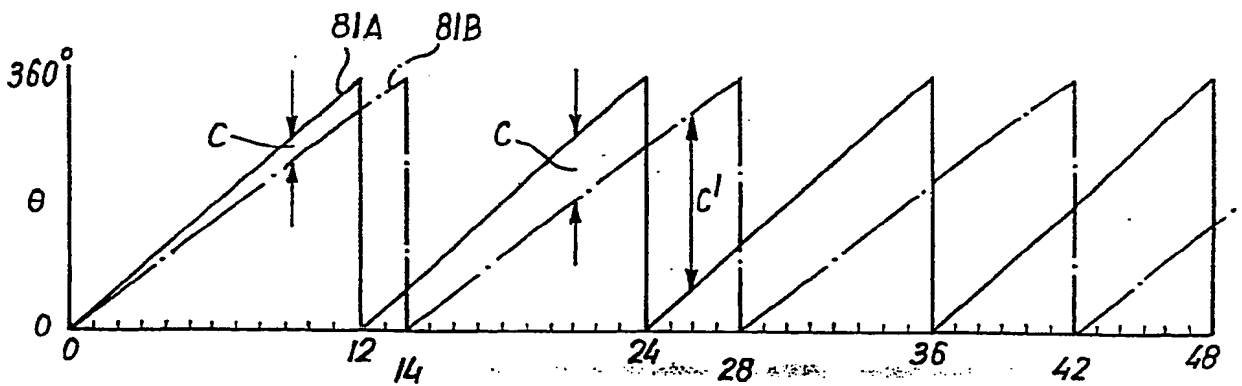
Fig.10
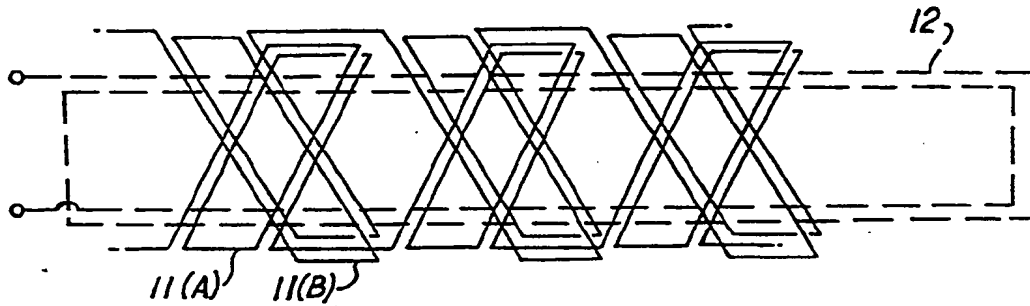
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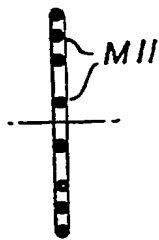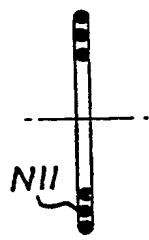
*Fig.12*M

*Fig.12*N

Fig.13

*Fig.14*A

*Fig.14*B

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FIG.12